AD-A095 175 NAVAL RESEARCH LAB WASHINGTON DC F/G 20/9
A PLASMA PROBE SYSTEM WITH AUTOMATIC SWEEP ADJUSTMENT.(U)
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NRL Memorandum Report 4424

A Plasma Probe System with Automatic Sweep Adjustment

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Ionospheric Effects Branch
Space Science Division

February 23, 1981

This work was supported in part by the Office of Naval Research under work unit 0949-0-0, and by the National Oceanic and Atmospheric Administration under contract NA79RAA04487.

NAVAL RESEARCH LABORATORY
Washington, D.C.

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: NRL Memorandum Report 4424

2. GOVT ACCESSION NO.: AD-A095 175

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle): A PLASMA PROBE SYSTEM WITH AUTOMATIC SWEEP ADJUSTMENT

5. TYPE OF REPORT & PERIOD COVERED: Interim report on a continuing NRL problem.

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s): J. C. Holmes [redacted] E. P. Szuszczewicz

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS: Naval Research Laboratory, Washington, DC 20375

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 61153N; RRØ33-02-44; 41-0949-0-1

11. CONTROLLING OFFICE NAME AND ADDRESS: Office of Naval Research, Arlington, Virginia 22217

12. REPORT DATE: Feb[redacted]81

13. NUMBER OF PAGES: 22

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report): UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This work was supported in part by the Office of Naval Research under work unit 0949-0-0, and by the National Oceanic and Atmospheric Administration under contract NA79RAA04487.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Plasma diagnostics
Plasma irregularities
Plasma instrumentation
Langmuir probes

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The capabilities of the pulsed Langmuir probe technique have been expanded to operate in charged particle environments having spatial and temporal variations in plasma or reference-electrode potentials. This practice is implemented by logic circuitry which tracks local floating potentials and adjusts automatically the sweep center voltage to guarantee a complete current-voltage characteristic with minimum sweep voltage excursion.

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A PLASMA PROBE SYSTEM WITH AUTOMATIC SWEEP ADJUSTMENT

INTRODUCTION

Interest in turbulent ionospheric and laboratory plasmas has resulted in the need for diagnostic devices with improved space and time resolution as well as multi-parameter (e.g., density, temperature and plasma potential) tracking. Historically, the Langmuir probe [1,2] has been one of the most widely used direct measurement techniques. Recent technical advances [3] extend its domain of operation into environments wherein the ambient plasma density can vary more quickly than the time required for the collection of a conventional current-voltage characteristic. This newer approach, referred to as a pulsed-plasma-probe or pulsed-Langmuir-probe, has been successfully applied in a number of investigations[4-6]; but more recent results from an Earth orbiting satellite and laboratory beam-plasma interactions have established the need for automatic sweep voltage control to cover changes in plasma or reference electrode potentials that approach or exceed the sweep voltage range of the Langmuir probe.

In a satellite application, the spacecraft itself is the probe's reference electrode and its potential is determined by the plasma density, temperature and ion mass as well as photoelectron emission and patterns of energetic particle precipitation[7,8]. Because these parameters vary widely over a given orbit, they determine the satellite potential and the absolute voltage range over which the probe is swept.

Manuscript submitted November 10, 1980.

Spacecraft potential can also be affected by bias voltages applied to conductors exposed to the ambient plasma (e.g., aperture plates of ion mass spectrometers and unshielded solar cell arrays) and by experiments employing on-board charged-particle guns. Spacecraft potential changes can be of magnitudes sufficient to preclude collection of a complete current-voltage characteristic; that is, probe operation may be only in one of the two saturation regions. Typical solutions to this problem involved large sweep excursions or commandable modes of operation which controlled the center voltage of the sweep. Both approaches have drawbacks.

Similar difficulties have been encountered in dc and pulsed electron-gun studies of beam-plasma interactions (Ref. 6 and follow-up investigations currently unpublished). In the dc mode the plasma potential showed a relatively large spatial dependence, while the pulsed gun operation resulted in strong temporal dependence. In both cases plasma potential variations have exceeded sweep voltage excursions considered optimum for the generation of a complete current voltage characteristic in mimimum time. In a completely Maxwellian plasma, that optimum excursion is nominally $40kT_e/e$, ranging between $V_- = V_f - 15\ kT_e/e$ and $V_+ = V_f + 25\ kT_e/e$. V_f is the probe floating potential, k is Boltzmann's constant, and e and T_e are the electron charge and temperature, respectively. For $T_e = 1000^oK$, an appropriate minimum probe voltage excursion would be 3.4 v ($= 40kT_e/e$) centered near $V_f = +\ 0.5$ volts.

An illustration of a nominal current voltage characteristic for this situation appears in Figure 1a where V_f was arbitrarily selected at 0.5 volts and the sweep excursion was selected at $\pm$ 2.5 volts centered on + 1.0 V. (We have found 0.5 V $\lesssim$ V_f $\lesssim$ + 1.0 V in most nighttime rocket- and satellite-borne probe investigations with passive diagnostic systems.)

Figure 1b illustrates the problem of changing reference potentials (reference electrode potential or plasma potential), a situation in which the reference electrode has become 3 volts more negative in potential (with respect to the plasma) than in Figure 1a. For the same sweep voltage excursion only ion-saturation currents are collected, resulting in the loss of information regarding electron energy, absolute density and plasma potential as conventionally determined from the retarding-field and electron-saturation portions of the characteristic[2]. In the self-centering-sweep logic to be described in the next section this condition is sensed by routine monitoring of the probe floating potential, and an automatic adjustment in the sweep-center voltage is made. The result is illustrated in Figure 1c.

APPROACH

Each probe voltage-sweep is a symmetric sawtooth having negative and positive going ramps. The sweep excursion is $\pm$ 2.5 volts about the sweep center voltage. During each positive going ramp, the automatic sweep feature records and stores the sweep voltage at which the probe is at floating

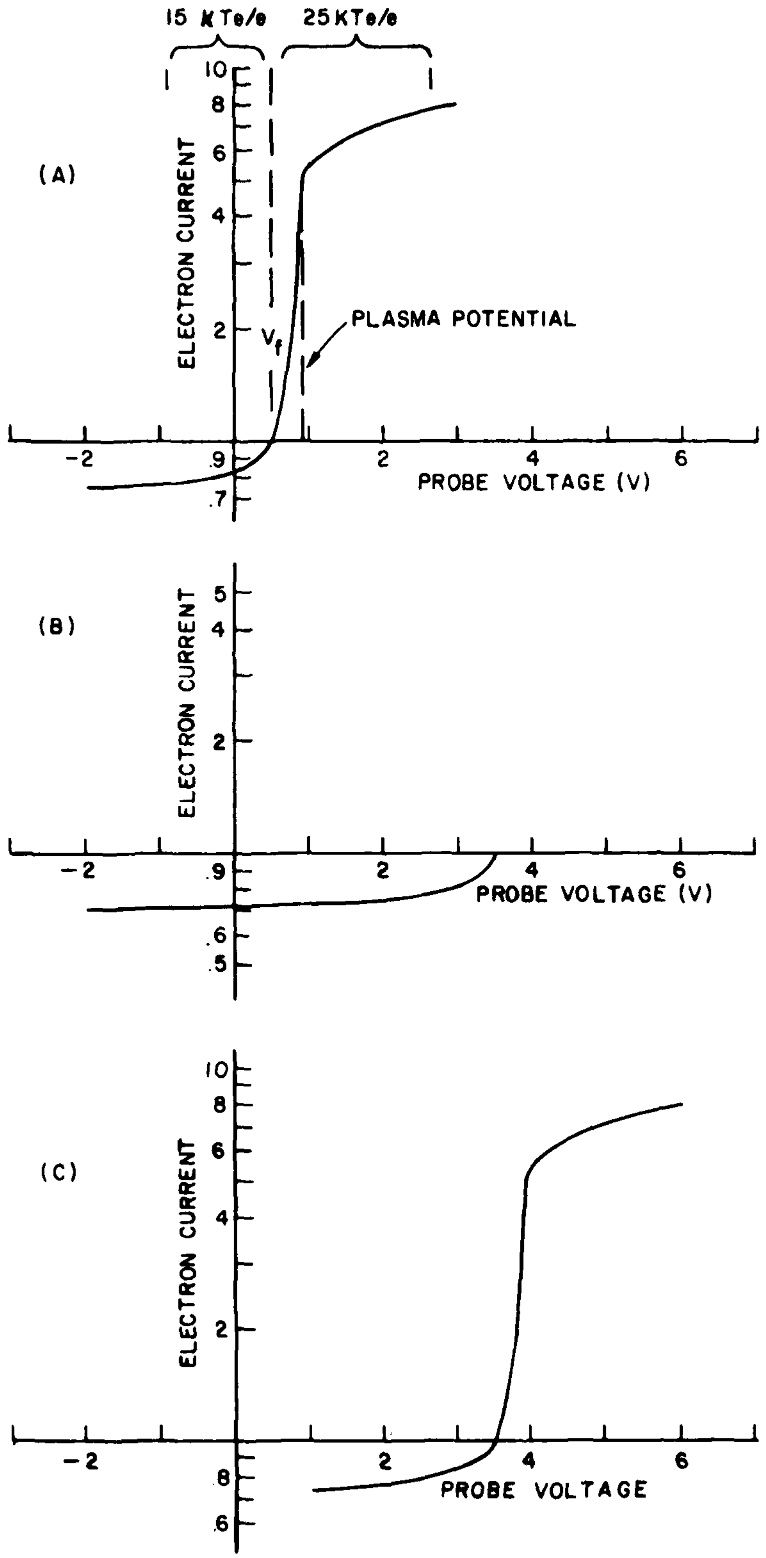


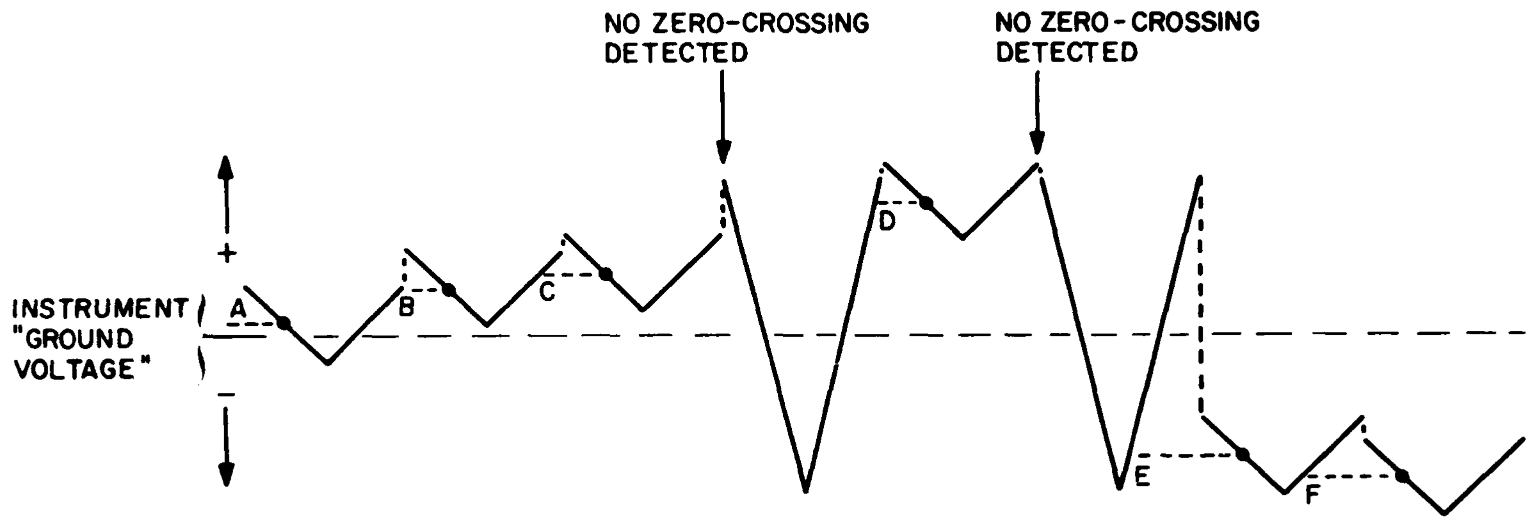
Fig. 1 — Langmuir probe current/voltage characteristics.

potential (in the case of a noisy characteristic, the last point of a zero probe current). At the commencement of the next negative going ramp, the sweep excursion is re-centered at the last recorded value of zero-current sweep voltage where it remains at least until the commencement of the next negative going ramp.

If no probe current "zero" is detected during a normal 5 volt positive going ramp (as would be the case if the ramp excursion covered only the electron or the ion saturation of a current voltage characteristic) then the next sweep will be a "search" sweep of $\pm$ 10 volts excursion. Following the detection of zero probe-current, the next sweep will be 5 volts in amplitude and centered at the newly discovered value of sweep voltage that corresponds to zero probe-current.

Figure 2 illustrates the automatic sweep centering operation on a space vehicle that has a time-dependent spacecraft potential. The horizontal dotted lines identify zero-current points on positive going sweeps. These zero-current points become center voltages of each following sweep pair.

During the first two pairs of normal 5 volt sweeps (Figure 2), zero probe-current crossings are recorded, and subsequent sweeps are centered accordingly at levels B and C. The third sweep encounters no zero crossing, so the following sweep pair excursion is $\pm$ 10 volts, and a successful search for zero-current crossing takes place on the positive



POINT A INITIAL ZERO CROSSING VOLTAGE
B VEHICLE POTENTIAL HAS DRIFTED − 2 VOLTS; NEXT SWEEP CORRECTS +2 VOLTS
C VEHICLE POTENTIAL HAS DRIFTED − 3 VOLTS; NEXT SWEEP CORRECTS +3 VOLTS
D VEHICLE POTENTIAL HAS DRIFTED − 8 VOLTS; NEXT SWEEP CORRECTS +8 VOLTS
E VEHICLE POTENTIAL HAS DRIFTED + 9 VOLTS; NEXT SWEEP CORRECTS − 9 VOLTS
F VEHICLE POTENTIAL HAS DRIFTED + 10 VOLTS; NEXT SWEEP CORRECTS −10 VOLTS

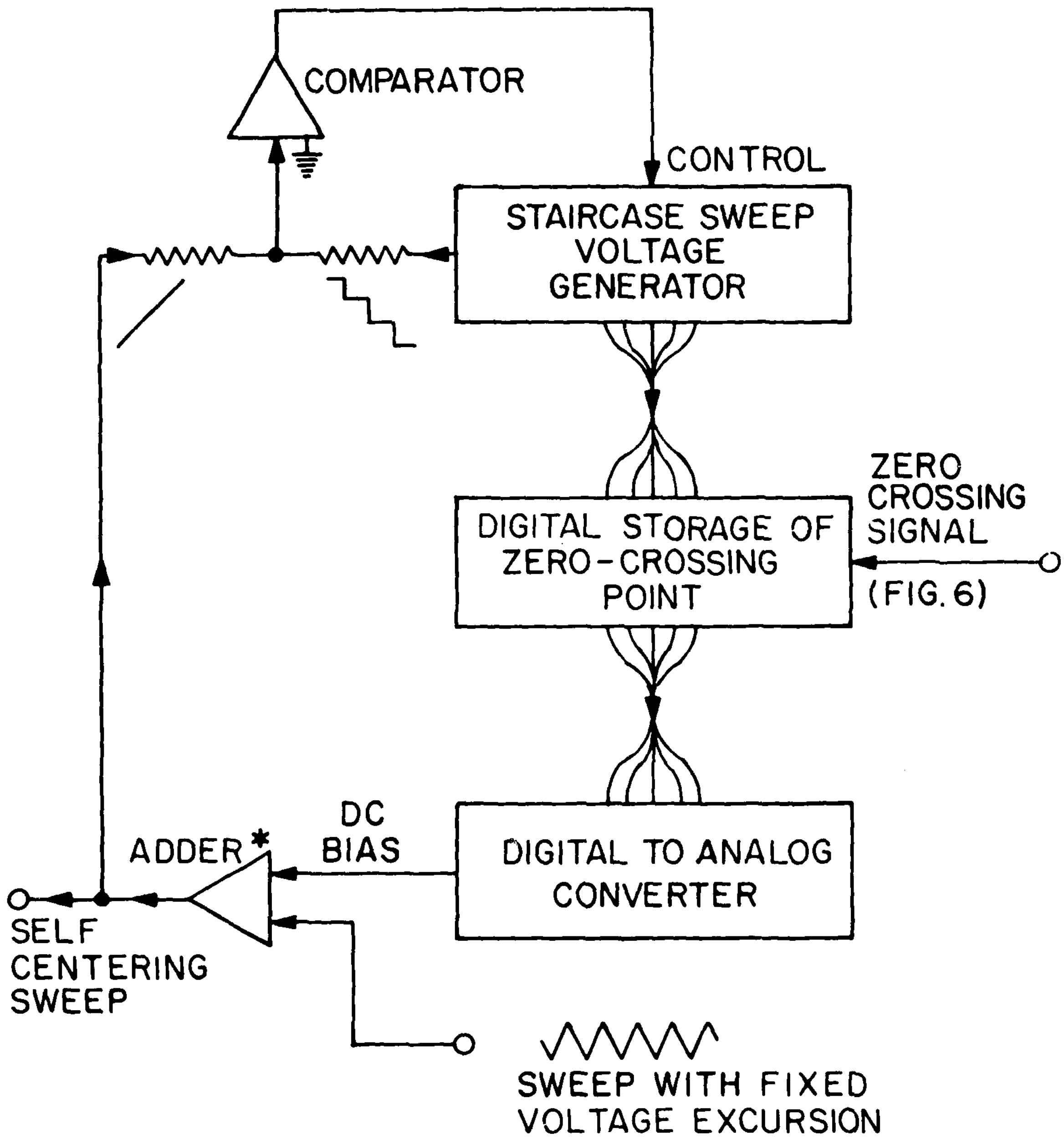
Fig. 2 — Self-centering sweep under conditions of changing spacecraft potential.

going sweep. The 5th sweep pair is so centered (at D), but no zero crossing is recorded on the positive going sweep. The next "search" sweep finds one at E, and the following E-centered sweep finds one at F.

Figure 3 is a simplified electronic explanation of the self-centering sweep circuit. A 5 volt peak-to-peak sawtooth sweep of fixed voltage excursion is algebraically added to a DC bias, the value of which is exactly the voltage by which the adder output is offset from zero. The adder output becomes the self-centering sweep voltage centered at the value of the DC bias.

A comparator forces a 6-bit digital staircase voltage generator to provide a stepped voltage that is an (inverted) image of the self centered sweep. From the probe current circuitry, a zero-current signal flag "freezes" in a D/A converter the digital representation of the sweep voltage (staircase step) at which the probe current is zero. The output of the D/A converter is itself the adder bias for the following sweep. For "search" mode operation, the bias is set to zero volts, and the gain of the adder is quadrupled.

Figure 4 is a picture of the sweep system. The digital staircase sweep generator is a CD4520 counter driven by a 5 kHz clock that is gated by the comparator. Clock pulse gates also prevent the counter from exceeding its maximum count. The 6 bit counter output is converted to an analog voltage by the 6-bit D/A converter. This voltage is the staircase



* TO PRODUCE "SEARCH" SWEEP, BIAS IS SET TO ZERO, AND THE GAIN OF THE ADDER IS QUADRUPLED

Fig. 3 — Simplified representation of self-adjusting sweep.

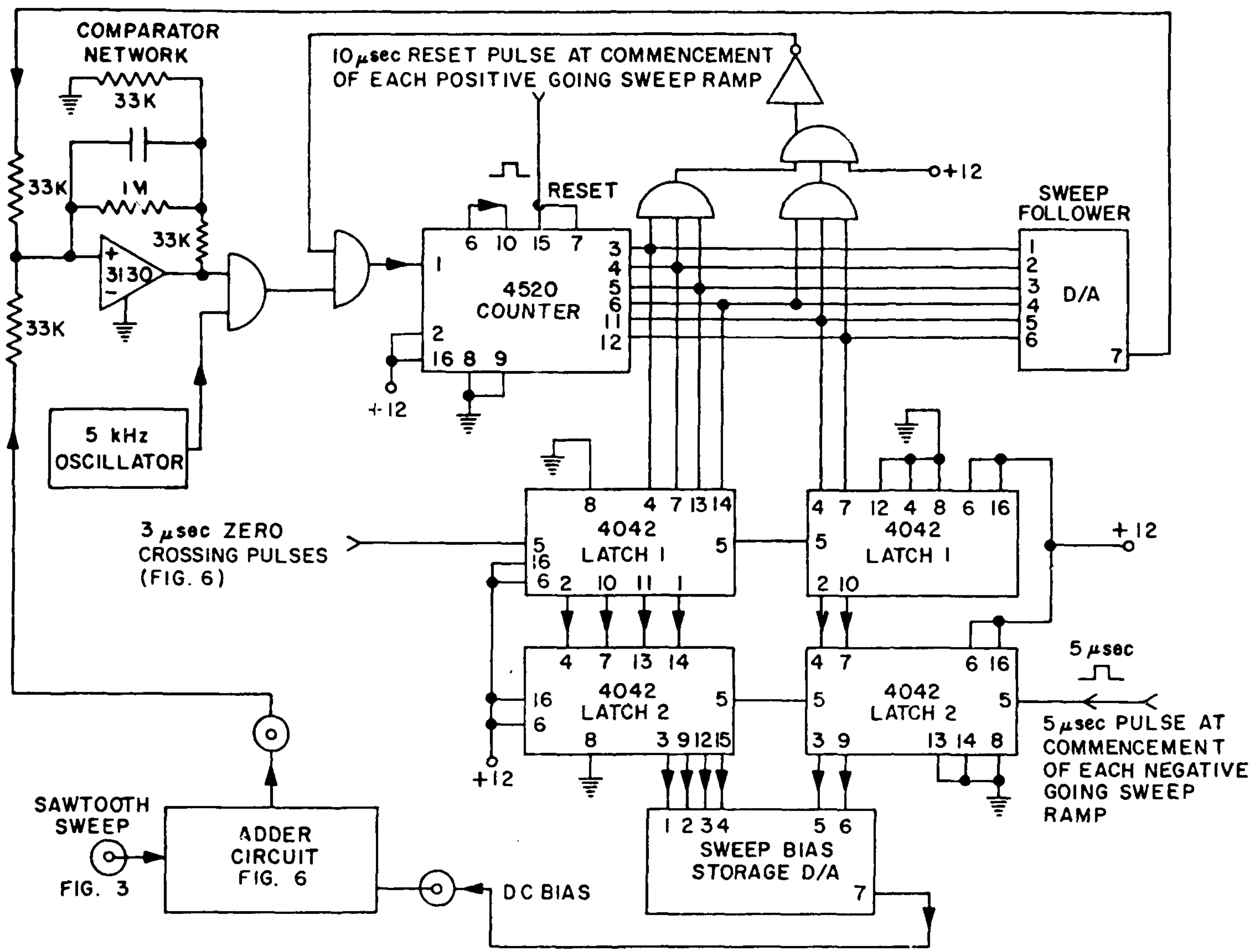


Fig. 4 — Self-adjusting sweep circuit details.

sweep that is forced by the comparator to follow the adder output sweep voltage.

When, during a positive going sawtooth ramp, the probe current changes from net ion current to net electron current (zero-crossing), a 3 μsec zero crossing pulse is generated (the method of its generation is discussed later). This pulse enables a double CD4042 latch (6 bits are used), and the digital equivalent of the staircase step corresponding to the sweep zero-crossing voltage is stored in six-bit Latch 1. If more than one such zero-crossing occurs, the last remains stored in the latch. At the commencement of each negative going ramp, a 5 usec pulse transfers the contents of Latch 1 into Latch 2. The inverted outputs of Latch 2 are the inputs to the sweep bias D/A converter. This D/A converter output voltage is the new value of sweep bias, and it remains fixed until it is changed at the commencement of some future negative going sweep. Meanwhile, Latch 1 is free to store new zero-crossing information which will ultimately affect the contents of Latch 2 only at the commencement of the double sweep immediately following the discovery of a new value of zero-crossing sweep voltage.

This staircase sweep and latch system thus serves as a digital sample-and-hold circuit that can store for indefinite periods the center voltage for the automatic sweep.

APPLICATION TO PULSED SWEEP OPERATION

The Langmuir probe system used by the authors features a short duty-cycle pulse modulated sweep (Figure 5) which

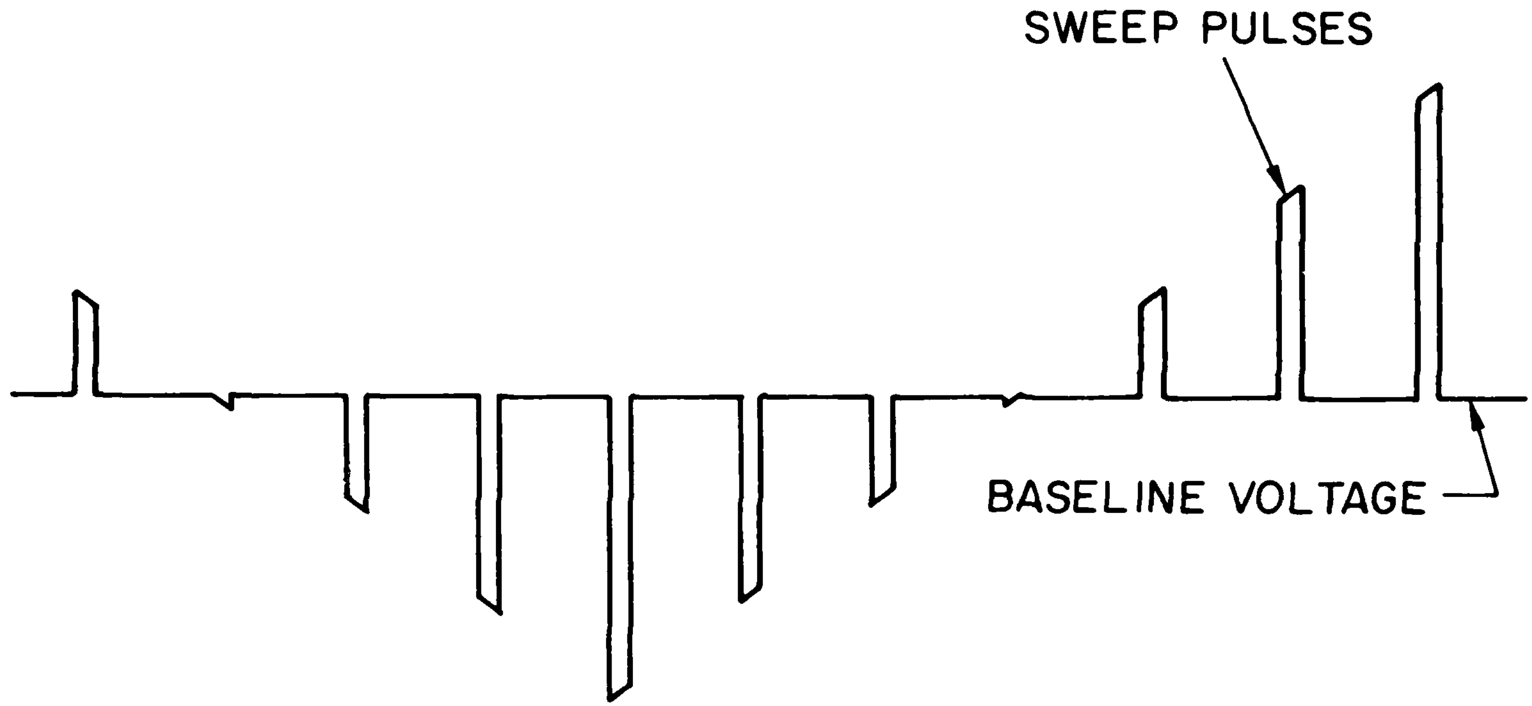


Fig. 5 — Pulsed Langmuir probe sweep.

follows a symmetric sawtooth envelope waveform of period about .7 seconds. Between pulses the sweep is returned to a constant voltage (baseline) where it rests until the next sweep pulse. The individual sweep pulses occur at a rate of about 500 Hz.

Computer calibration of the instrument is in real time so that errors from displacement current charging of the Langmuir probe capacity are part of the calibration. This calibration simulates a plasma using a number of fixed resistors that range from 10^9 to 10^4 ohms. Such a calibration procedure shows negligible differences (hysteresis) between negative and positive going sweeps. Hysteresis found in a plasma environment using this pulsed probe technique is assumed to be from severe contamination of probe surfaces. To completely overcome any such potential problem would require the sweep pulses to have a duty cycle of zero.

Under normal operation, probe current is sampled both during sweep pulses as well as during the baseline voltage interval. (In the original design[3], baseline currents were measured only during a blanked-out pulse. All subsequent designs have restored the blanked-pulse and baseline currents are measured during baseline periods.) Baseline current measurements are a monitor of the instantaneous value of plasma density. Plasma temperatures derived from swept Langmuir probes are accurate only when correction is made for plasma density changes that take place during a voltage/current sweep[4-6]. Also, voltage/current characteristic distortions caused by probe surface contamination are minimized when the pulse duty cycle is short[9].

To implement the automatic self centering sweep using pulsed sweep technology, the sawtooth sweep generated at the output of the adder (Figure 3) is sent to a modulator where segments are chopped from the sawtooth sweep (Figure 5). The modulator is simply a CMOS switch controlled by a 100 usec pulse having, in this case, a repetition rate of approximately 600 Hz.

In pulsed sweep mode operation, the Langmuir current/voltage characteristic is derived from the probe current samples taken during sweep pulses. Consequently, the probe-current reversals (zero crossings) that occur from sweep-pulse to sweep-pulse must be separated from reversals that occur between sweep samples and baseline samples. This is accomplished by storing the probe current polarity present during each sweep pulse in a type D flip-flop (Figure 6). The flip-flop transitions thus occur only for "true" probe current reversals. These transitions trigger a 3 usec one-shot multivibrator, the pulses from which enable Latch 1 (Figure 4) to store the digital equivalent of the zero-crossing sweep voltage.

If no 3 μsec zero-crossing pulses occur during a positive going sweep, then the sweep mode controller (Figure 7) through the AD7512 mode switch places the sweep in search mode by centering the sweep at zero volts and quadrupling the normal sweep excursion. When zero crossings are detected, the sweep amplitude is returned to normal, and the sweep is centered at a new DC voltage supplied by the Sweep Bias Storage D/A converter (Figure 4).

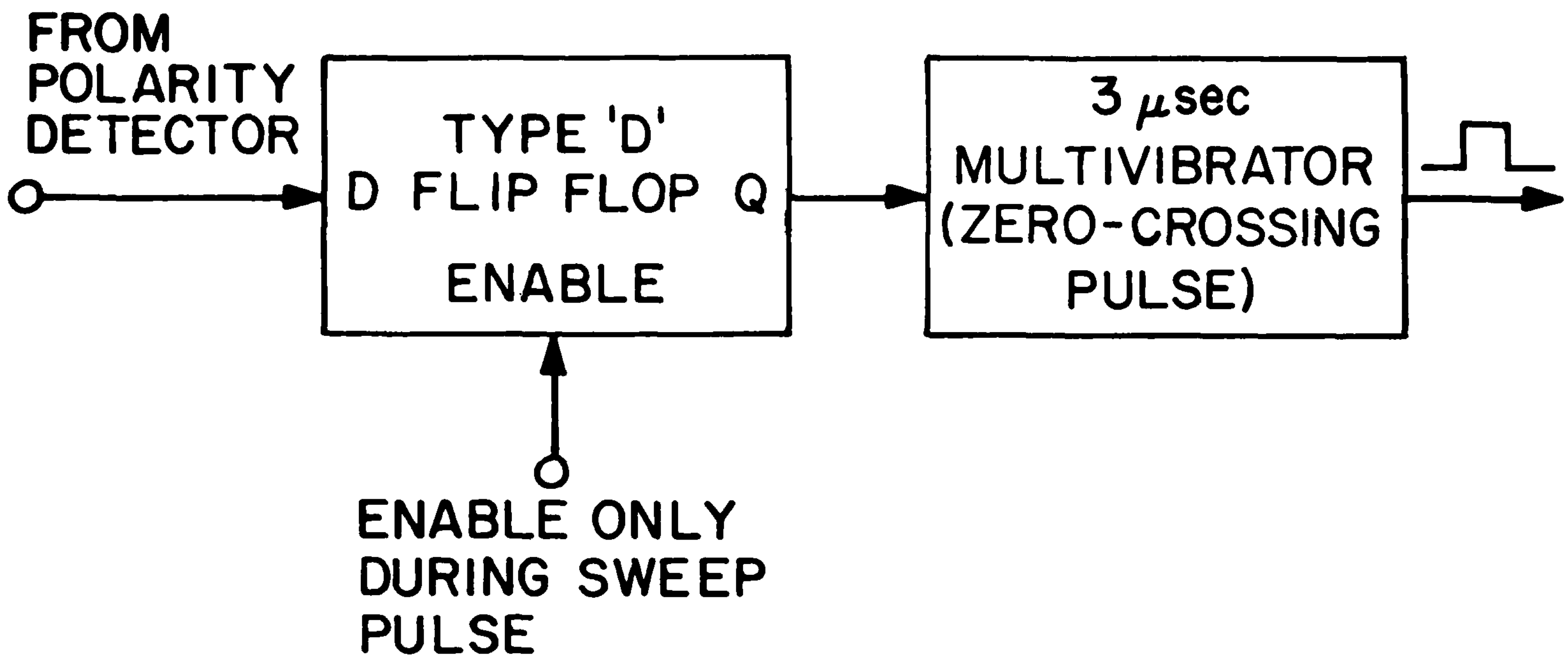


Fig. 6 — Zero-crossing pulse generator.

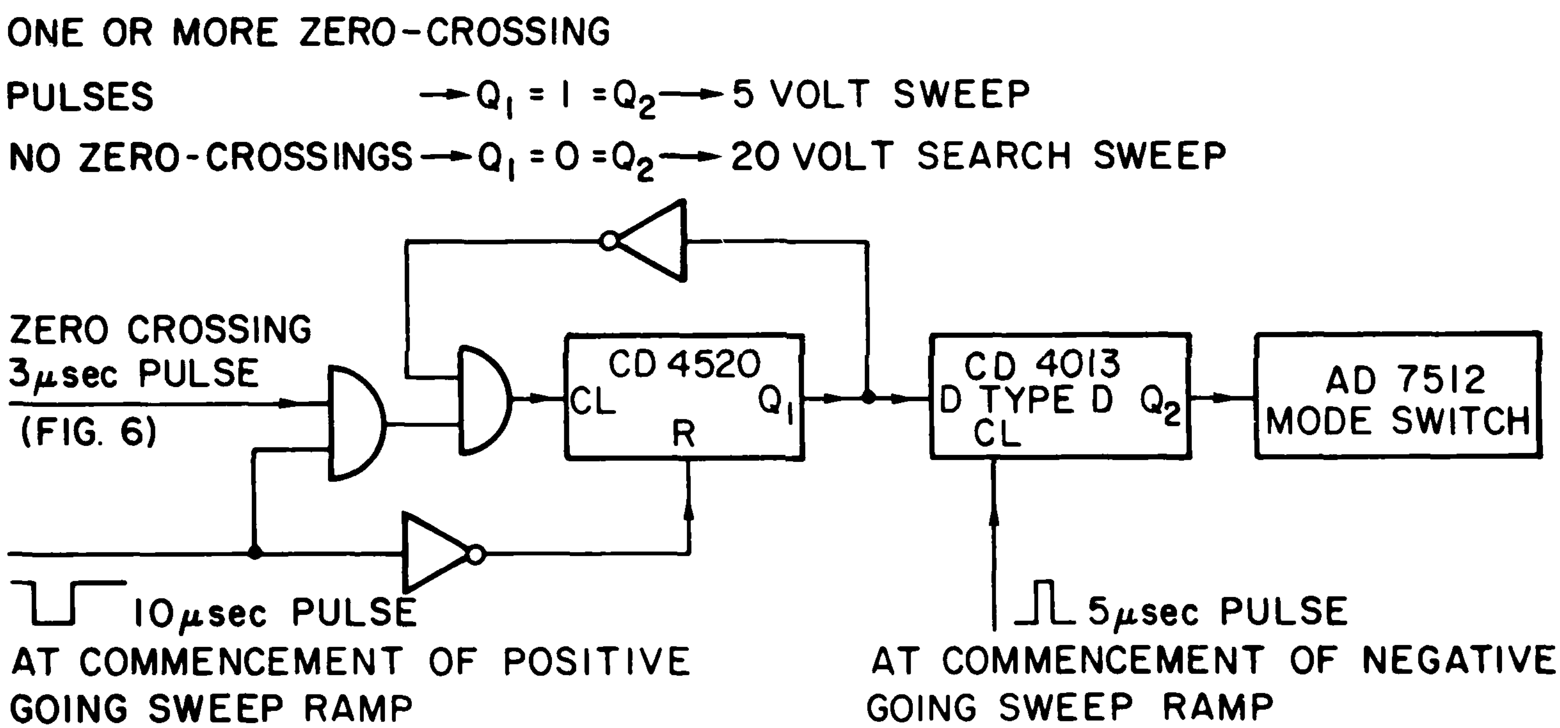


Fig. 7 — Sweep mode controller.

The 3 usec zero crossing pulses clock a CD4520 flip-flop. A single zero crossing pulse closes the clock pulse gate and leaves the CD4520 Q_1 output at 1 until reset occurs at the commencement of the positive going sweep ramp. At commencement of the negative going sweep ramp, a 1 at the CD4520 output is transferred to the Type D fiip-flop, and the mode switch remains in the normal sweep mode. If a "0" (meaning no zero crossing pulses detected) is transferred to the Type D, then the next double sweeps will be in the search mode until a zero-crossing comes along.

EXPERIMENTAL WORK

Analysis of current-voltage characteristics from laboratory, earth satellite, and rocket Langmuir probe investigations have demonstrated the need for automatic control of probe sweep centering in situations where manual adjustment of sweep voltage offset is inconvenient or impractical.

The pulsed Langmuir probe installation on earth satellite STP-S3-4 experienced a probe floating potential change of more than 5 volts when electrically exposed satellite solar panels were illuminated by sunlight. This situation, unknown to experimenters prior to launch, obliterated Langmuir characteristics during daylight portions of the satellite orbit. At night, the total floating potential variation of the pulsed probe was typically 3 volts over the dark side of the earth; within 20^{o} of the magnetic equator where ionospheric plasma variations can be very intense, the typical change was 1.5 volts and local variations of up to 200 mv/second were measured.

During a portion of a rocket flight into the auroral ionosphere (NASA 33.004, 2/26/79), an on-board Langmuir probe registered 2 volt changes in probe floating potential which were sufficient to eliminate zero values of probe current. In October 1979, the Naval Research Laboratory instrumented the Johnson Space Center Beam Plasma Discharge chamber with a pulsed probe which registered time dependent probe floating potential changes of up to 12 volts. Spatial variations from probe movement through the plasma were measured up to 100 mv/second. Adjustment of the probe sweep bias was manual, and it was sometimes impossible to correct for probe floating potential shifts in time to acquire the current/voltage characteristics desired.

In March 1980, new experiments were conducted at the Johnson Space Center facility for which the Langmuir probe had been modified to incorporate the self-centering sweep design. Sweep centering corrections of up to 10 volts were made within a single double-ramp (a maximum of .8 seconds).

On January 26, 1980 at Poker Flat, Alaska, a research rocket (NASA 29,014) carrying particle and field detectors, an ion thruster, and a pulsed plasma probe was launched into the nighttime ionosphere. The ion gun was fired periodically for several seconds, and during the lowest altitude gun pulse, the probe floating potential changed 10 volts in about as many seconds. The automatic sweep centering feature followed this change such that at no time did the probe floating potential fall outside the probe's sweep voltage excursion.

This experimental work has verified the utility of automatic control of sweep voltage for a Langmuir probe for many plasma environments including the natural and artificially-controlled ionosphere. The authors plan to utilize this device as standard practice both under laboratory conditions where changes in plasma characteristics are fast, and in remote situations (rocket and satellite) where operator control has either limited response capability or does not exist.

ACKNOWLEDGMENT

Support for instrument design and development was provided in part by the Office of Naval Research under Work Unit 0949-0-0, and by the National Oceanic and Atmospheric Administration under contract NA79RAA04487. We also wish to acknowledge the dedicated technical support of L. Kegley and M. Swinney during fabrication and test phases, and the diligent assistance of Drs. D. Walker and C. S. Lin in the computer calibration phase.

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